1954

Operations analysis for General Line School officers

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Monterey, California: U.S. Naval Postgraduate School

http://hdl.handle.net/10945/14475

OPERATIONS ANALYSIS FOR GENERAL LINE SCHOOL OFFICERS

MARVIN IRVING ROSENBERG

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OPERATIONS ANALYSIS
FOR
GENERAL LINE SCHOOL OFFICERS

MARVIN IRVING ROSENBERG

OPERATIONS ANALYSIS

FOR

GENERAL LINE SCHOOL OFFICERS

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Marvin I. Rosenberg

OPERATIONS ANALYSIS FOR GENERAL LINE SCHOOL OFFICERS

by

Marvin Irving Rosenberg
Commander, United States Navy

Submitted in partial fulfillment
of the requirements
for the

CERTIFICATE OF COMPLETION
in the
OPERATIONS ANALYSIS CURRICULUM

United States Naval Postgraduate School
Monterey, California
1 9 5 4

This work is accepted as fulfilling
the requirements for the

CERTIFICATE OF COMPLETION

in the

OPERATIONS ANALYSIS CURRICULUM

PREFACE

The equipment and personnel available to a military commander to accomplish his mission are limited now and will be limited in the future. He will have to evaluate his needs more exactly and will have to find a way to make more efficient use of what is available. He will have to find a way to "optimize his achievement of purpose" -- he will have to make use of Operations Analysis.

The writer of this paper is convinced of the great importance of Operations Analysis in our military effort. He feels that increasing numbers of naval officers should know about Operations Analysis. His purpose is to write a non-technical paper that tells the General Line School student about Operations Analysis. The achievement of this purpose is optimized by a wide distribution of this paper among naval officers.

This paper was written at the U. S. Naval Postgraduate School during the latter half of the academic year 1953-1954.

The writer would like to express his appreciation to Professors C. C. Torrance, W. P. Cunningham and T. E. Oberbeck of the United States Naval Postgraduate School staff for their guidance.

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CHAPTER I

INTRODUCTION

The purpose of this paper is to present information concerning Operations Analysis in non-technical language. It will show how this subject helps the naval officer. It will show that the average naval officer does in fact make use of Operations Analysis in many of his duties.

This paper is divided into the following chapters:

I Introduction

II Definitions, methodology, background of Operations Analysis

III Organizations involved in Operations Analysis

IV Examples of Operations Analysis and concepts used

V Training in Operations Analysis

VI An Operations Analysis problem for the reader

VII Classified Sources of Information

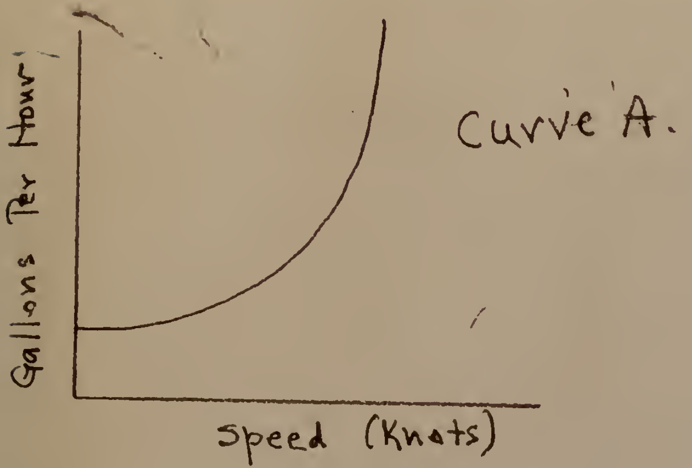
CHAPTER II

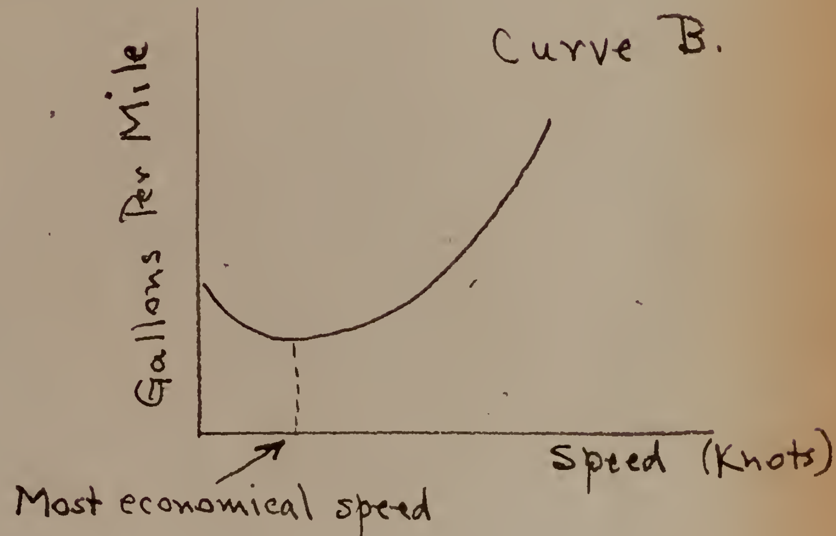
DEFINITIONS, METHODOLOGY, BACKGROUND OF OPERATIONS ANALYSIS

One definition of Operations Analysis is the following: "Operations Analysis is the application of scientific method in the study of repeated operations to provide quantitative basis for executive decision". Another definition states, "Operations Analysis optimizes the achievement of purpose." The full significance of these definitions will be indicated as this paper develops. It appears that one important thought is to provide an aid to an executive who must make a decision. This aid must be one based upon logic and an objective approach, rather than being based upon intuition alone, which of course may be wrong.

At this point it might be well to digress and cite a concrete example of Operations Analysis. This example is one that has confronted many Naval Officers. The question is: "At what speed should your ship (or plane) travel in order to cover the greatest distance?" In most cases the answer is readily available--it is merely a case of comparing the most economical speed with the quantity of fuel available. This of course means finding that number of gallons per mile which is the minimum, and then traveling at the corresponding speed. Suppose that <u>only</u> the following information was available: "A graph showing fuel consumption in gallons per hour at different speeds (curve A)". How then would you determine the speed to be used in order to "Optimize the achievement of your purpose", which is to travel the greatest distance? An approach would be to plot a curve of <u>gallons per mile</u> versus speed, using the

data from Curve A. The minimum point of the new curve would give the proper speed to be used (Curve B).





This example is not complex. In fact most of the required data has already been worked out for planes and most ships. Nevertheless it shows a method of "optimizing the achievement of purpose"-- it furnishes a logical numerical answer to the person who must make a decision.

Next, an example of Operations Analysis on a larger scale will be described. This concerns the German U-boat campaign against the British during the winter of 1941-1942. During this period of increased U-boat activity the British were not being very successful in destroying those U-boats which were operating off the English coast. The patrol planes were sighting many U-boats on the surface and were attacking them with depth charges, yet the percentage of submarines actually sunk was too small. Some civilian scientists were called in to make an analysis of these operations. They found that current doctrine called for the depth charges to be set at 100 ft. A setting of 100 ft. had been selected because of the greater lethal radius of a depth charge at that depth. Considering the point of reference to be the swirl left by a submerging U-boat, they analysed the possible positions of the sub at different times after submerging. Since the U-boat was moving through the water as he submerged, the area of his possible positions would increase with an increase in time submerged. The area of his possible positions at 100 ft. depth was much larger than the area of his possible positions at 25 ft. depth. This meant that the probabilities of hitting him with a depth charge exploding at the greater depth were greatly diminished.

The following data concerning previous attacks was obtained and analyzed:

Condition of U-boat	Percentage of all attacks
U-boats visible	34
Submerged up to 15 sec.	27
Submerged 15 to 30 sec.	15
Submerged 30 to 60 sec.	12
Submerged more than 60 sec.	11

This shows that about 60% of the targets attacked were on the surface or had been submerged for periods up to 15 sec. The submarines submerged at the rate of about 2 ft. per second when diving. Therefore, more than half of the submarines attacked were at depths between 0 and 30 feet. It seemed logical to increase the probability of hitting U-boats by setting the depth charges to explode at shallower depths. This seemed better even if the lethal radius was decreased with shallower depth setting. This analysis bore fruit in the increased number of U-boats sunk when a depth setting of 25 feet was used. As a result of this Operations Analysis the number of U-boats sunk increased until it reached the figure of twenty per month within one year.

A generalized methodology for solving an operations analysis problem is as follows:

FORMULATE THE PROBLEM

1. State the objective of the action.
2. Enumerate the alternatives
3. Define a measure of effectiveness for comparing alternatives.

SOLVE THE PROBLEM WHICH HAS BEEN FORMULATED, BY MEANS OF:

1. Theoretical methods (pencil and paper). Model technique.
2. Conduct trials or controlled experiments.
3. Analyze records.

It is to be noted that the above methodology is merely a logical approach to solving an Operations Analysis problem. In the U-boat example cited above, the objective of the action was to sink as many U-boats per unit time as possible with the weapons system (aircraft) in effect. The alternatives were depth settings of the depth charges or combinations of these settings. The measure of effectiveness was "Number of U-boats sunk per month." This analysis was made by studying past records. It is to be noted that the analysts made a

recommendation to the administrator (The British Coastal Command). This recommendation was based upon a definite measure of effectiveness. It gave to the command a definite method for optimizing achievement of purpose.

It is to be noted that higher mathematics was not necessary to make this analysis. However, there are many Operations Analysis problems which require concepts developed by higher mathematics.

The general subject of Operations Analysis received its biggest impetus during World War II when the military called upon civilian scientists to help "maximize the achievement of purpose". Various organizations were developed in governmental agencies and in industry. The next chapter describes in general terms the outstanding operations analysis organizations as they exist today in the armed services. At times the term "Operations Research" is used. This is a term used by some persons and is interpreted to mean "operations analysis".

CHAPTER III

ORGANIZATIONS INVOLVED IN OPERATIONS ANALYSIS

1. U. S. NAVY

In the U. S. Navy there is an analysis group called The Operations Evaluation Group. It consists of about 60 civilian scientists located in the Pentagon Building. It is an organization within the framework of the organization of the Office of the Chief of Naval Operations. The Director of The Operations Evaluation Group comes under the purview of the Director of New Developments and Operations Evaluation Division, who in turn comes under the Deputy Chief of Naval Operations (Operations). At this writing the Director of the Operations Evaluation Group is Dr. J. Steinhardt. He and all the other civilian scientists that make up this activity are actually employed by the Massachusetts Institute of Technology. The Massachusetts Institute of Technology is under contract to the U. S. Navy.

The Operations Evaluation Group is divided into the following sections: (1) Undersea warfare and Overseas transport; (2) Air warfare; (3) General warfare, including radar and CIC. The individuals of this organization maintain personal liaison with the other activities of the Office of the Chief of Naval Operations.

The Operations Evaluation Group also have representatives outside of Washington, D. C. The following are the major field assignments: a representative at each of the following activities: First Marine Air Wing; Seventh Fleet; Commander Naval Forces

Far East; Pacific Fleet Evaluation Group, at Pearl Harbor; Operations Development Force at Norfolk; Surface Anti-Submarine Development Detachment at Key West; ZX-11 at Key West; VX-3 at Atlantic City; VX-4 and VX-5, at Point Mugu; Sixth Fleet; Naval War College, at Newport. This enables the personnel of this group to maintain close contact with activities in the fleet. There is an overall plan for rotation of these civilian scientists so that they will have a proper amount of time in the field, in the Pentagon, and back in their teaching or research jobs at the Massachusetts Institute of Technology, at Cambridge. In general the specialties of the members of this group are those of physics and mathematics.

2. U. S. AIR FORCE

The operations analysis group in the U. S. Air Force is designated "The Operations Analysis Division". At present the Chief, Operations Analysis Division, is Dr. LeRoy A. Brothers. He and his organization come under the Deputy Chief of Staff, Operations, who in turn comes under the Chief of Staff, U. S. Air Force. The members of this group are also civilian scientists. There are about 30 of them, located in the Pentagon Building. They are employed by the U. S. Government (civil service). Members of this group are also assigned to field activities. In addition to the group in the Pentagon, there are others assigned to the Strategic Air Command, the Tactical Air Command, the Air Defense Command, the Alaskan Air Command, the Allied Air Forces Central Europe, and the Far East Air Force. The backgrounds of this group are varied too; they include those of mathematics, physics, law and others.

There is another independent activity which does analysis work for the U. S. Air Force. This is the RAND Corporation, located at Santa Monica, California. This is a private corporation under contract to the U. S. Air Force. The types of projects it handles are long range in contrast with the types of projects undertaken by the Operations Analysis Division.

3. U. S. ARMY

The corresponding analysis organization of the U. S. Army is designated "The Operations Research Office". This consists of about 140 civilian scientists who are employed by Johns Hopkins University. Johns Hopkins University is under contract to the U. S. Army. This organization is located on Connecticut Avenue in Chevy Chase, Maryland. The Director of the Operations Research Office is Dr. E. A. Johnson. There are also representatives assigned to the Far East Command, in European commands and at Fort Monroe. Here also the backgrounds of the members of the group are varied; they include those of physics, mathematics, economics, psychology, history. The Director of the Operations Research Office comes under the purview of the U. S. Army's "G-3".

4. DEPARTMENT OF DEFENSE

Another analysis organization is designated "The Weapons Systems Evaluation Group". This is an organization which concerns itself with higher level problems presented by the Department of Defense and the Joint Chiefs of Staff. It is located in the Pentagon Building. This activity comes under the Secretary of Defense. At present the

Director of the Weapons Systems Evaluation Group is a Lt. Gen. G. Keyes, USA. The Deputy Director of Research is Dr. E. Bright Wilson. This organization is composed of about 30 military officers (from the three services) and about 30 civilians. These civilians are civil service employees of the U. S. Government. This activity "borrows" persons with the required backgrounds from other agencies when necessary to solve certain problems confronting them.

Every two or three months there is held a joint seminar of the Operations Evaluation Group, the Operations Analysis Division, The Operations Research Office and the Weapons Systems Evaluation Group. There are also analysis organizations in Canada and in England. Our government maintains liaison with them too.

5. OPERATIONAL DEVELOPMENT FORCE

A large Naval Activity involved in operations analysis and development is the Operational Development Force, U. S. Atlantic Fleet. Its mission is promulgated in OPNAV INSTRUCTION 5440.47 of 5 January 1954. Paragraph 7 of this instruction is quoted below:

"7. Mission of Operational Development Force. The mission of the Operational Development Force is restated as follows:

a. To evaluate by operational test and to report on:

(1) The problems arising from the proposals for and development and introduction into the fleet of new weapons, new equipment, and new methods of employment.

(2) The problems arising from the effort to secure more effective use of standard equipment and weapons currently installed in the fleet.

b. To recommend training procedures, training aids, countermeasures, and changes in tactical doctrine incident to (1) and (2) above.

c. To assist, with services and facilities, naval and extra-naval agencies engaged in (1) and (2) above."

6. THE OPERATIONS RESEARCH SOCIETY OF AMERICA.

Another indication of the growth of operations research is in the recent founding of the Operations Research Society of America. This is a civilian organization which was founded by a group of scientists who had been doing work in that field and who recognized its importance to the military and civilian pursuits. The first Society meeting was held on May 26, 1952, in New York. In the summer of 1953 there were approximately 500 members of the Operations Research Society of America.

The object of this organization is quoted below:

"The object of the Society shall be the advancement of the science of operations research, through exchange of information, the establishment and maintenance of professional standards of competence for work known as operations research, the improvement of the methods and techniques of operations research, and the encouragement and development of students of operations research."

The Journal of the Operations Research Society of America is published quarterly.

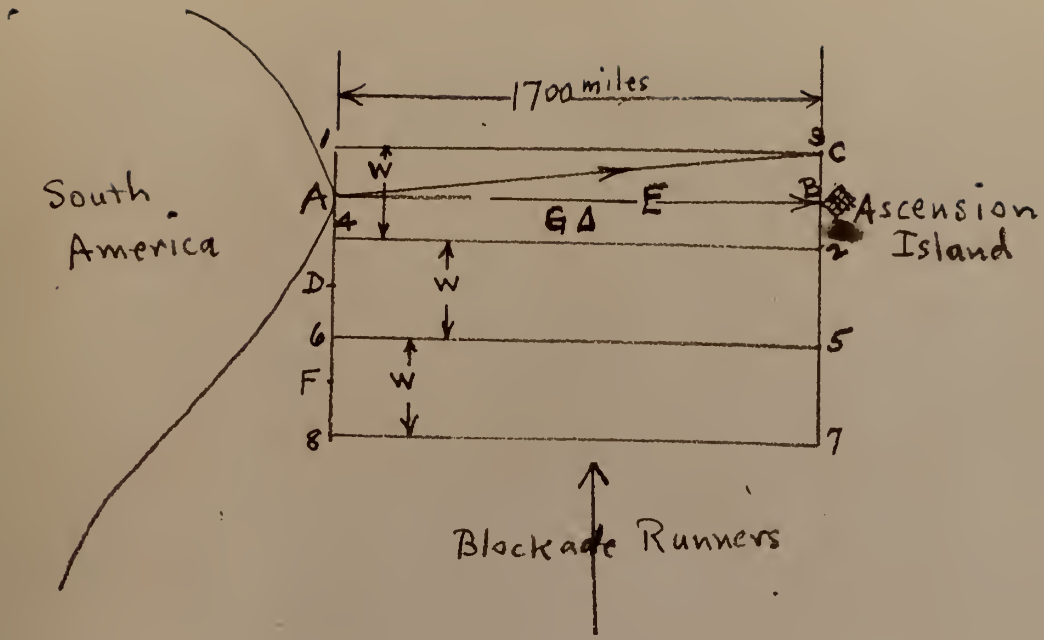
CHAPTER IV

EXAMPLES OF OPERATIONS ANALYSIS AND CONCEPTS USED

1. CAPTURE OF GERMAN BLOCKADE RUNNERS IN THE SOUTH ATLANTIC IN WORLD WAR II.

Operations Analysis provided a method for locating German blockade runners during World War II. The Fourth Fleet was assigned the task of locating and destroying the German blockade runners, which were carrying tin, rubber and other strategic necessities on their homeward trip from Japan. These German ships had to go up the east coast of South America and pass through a 1400 mile stretch of ocean between Brazil and Ascension Island. The problem confronting the Fourth Fleet was "which search plan will most effectively locate the blockade runners which might be anywhere in a very large area of the South Atlantic Ocean?" A civilian representative of the Navy's analysis organization was called upon to help solve this problem. He devised a plan which was so effective that it permitted intercepting practically all the blockade runners. The next paragraph indicates in general terms the development of this plan.

The assumptions made were that the blockade runners would travel at their maximum speed. Also all these vessels had to pass through a barrier lane between the eastern tip of South America and Ascension Island. The problem then resolved itself into development of a search plan (using aircraft) which would cover this lane for all blockade runners moving through it at any and all times. This included times of inclement weather and darkness.



In the accompanying sketch note the line AB, which shows the direct line connecting the east coast of South America with Ascension Island. A pilot flying east could see a definite distance on either side of his track. This determines his "sweep width" indicated "w" in the sketch. In flying from A to B the pilot would then sweep out an area between A and B. This area was w miles wide. First, consider a stationary ship G in this area. If a searching aircraft with sweep width "w" desired to locate this ship, he would fly the line AB and be sure to see the target. Next, suppose the target G were moving north. Now the plane would have to fly some course AC such that the component of his true course in a northerly direction exactly equalled the best estimated speed of the blockade runner (which was steaming north). In doing this the plane would

sweep out the same area of width w and length AB. By the time the plane had reached point "3" the area 1423 would have moved up a distance w. This meant that area 1423 had been searched for any shipping. Next, area 2564, which had moved up, was to be searched. Since the speed of the plane was so much greater than that of the expected target, he could fly south a distance and then fly on a northwesterly course so as to sweep out the next area 2564. This type of search plan would permit the searching planes to sweep out all areas moving north, and it would therefore assure the intercepting of all targets moving north at the estimated speed. By using more than one plane and by varying the distances and courses they flew it was possible to sweep out larger areas so that it was necessary to fly only during daylight hours. Also, corrections could be made for errors in target speeds. By using a search plan similar to the above, the Fourth Fleet was able to intercept the blockade runners without using an excessive number of planes or ships.

2. BAY OF BISCAY ANTI U-BOAT OFFENSIVE.

After the Germans had captured ports on the Bay of Biscay they operated their U-boats from them. The British were confronted with the problem of locating and destroying the U-boats which were enroute between their bases in the Bay of Biscay and their patrol areas. The U-boats were countering the British radar by "listening" and diving before the British were able to pick up the radar echo. This meant that one of the big problems confronting the British was

location of the U-boats. A U-boat's storage batteries would not permit submergence for more than four hours, during which the U-boat would move a certain maximum distance. If a plane could be flying in the vicinity of where a submarine was surfacing to charge his batteries, the plane might be able to attack the sub. If the sub has resubmerged, then subsequently he must surface sooner because he hadn't completely recharged his batteries. The area of his possible positions after this would be smaller than before. A properly designed patrol plan would cause a greater percentage of the U-boats to be on the surface due to inability to charge their batteries completely. This in turn would mean more sightings and more kills. Such a plan was developed by the British. Sightings increased to about 20 per week. Since they were averaging one kill in every ten sightings, they were able to effect about two kills a week by using this plan.

3. ONE THOUSAND PLANE RAIDS

During World War II the British made an analysis of the large scale bombing against selected German cities. They were trying to drop the greatest number of tons of bombs on the targets with the least cost to themselves. This cost showed itself of course as the number of bombers shot down by the German defenses. This meant that a "measure of effectiveness" was:

$$\frac{\text{tons of bombs on target}}{\text{number of own aircraft lost}}$$

To increase the above ratio means to "optimize the achievement of purpose", so far as the British were concerned. The analyses showed that beyond a certain number of planes participating in a

raid the number of bombers shot down remained fairly steady for each raid. This meant that the German defenses were being saturated. On the basis of this analysis the number of planes per raid was increased. This of course would mean a smaller percentage of planes shot down per raid. Consequently the measure of effectiveness would increase numerically. In 1942 the RAF made the first thousand-plane raid. This raid and subsequent large raids confirmed the correctness of this analysis.

4. LARGE MERCHANT-VESSEL CONVOYS.

It is common knowledge that during World War II we used large convoys of merchant-vessels, but few people know exactly why these large convoys were used. Intuitively it may appear to be better. However the military authorities needed more than intuition in deciding what size convoys should be used. Data was collected, and an analysis was made. It was found that the average number of ships sunk in a convoy was fairly constant, regardless of the size of the convoy. Here again, the probability of any one ship being sunk would decrease with an increase in the number of ships in a convoy. It was found that the percentage casualties, K, was given approximately by the equation,

$$K = e/nd$$ where e is a constant, n is the number of ships in the convoy, and d is the number of escorts. Here again was a measure of effectiveness. The percentage of ships sunk was decreased by increasing the sise of the convoy and increasing the number of

escorts when they were available. Once more the military authorities had a mathematical analysis which enabled them to make a far reaching decision. As a result of the above analysis the percentage of ships lost was greatly diminished.

5. BOMBING OF JAPAN

The importance of Operations Analysis was demonstrated in World War II at the time the U. S. was using B-29's to bomb Japan. Here the achievement of purpose was to drop many tons of bombs on the target. The analysis demonstrated a way to increase the number of tons of bombs on the target to its optimum value. At first the total flying time was divided up as follows: 4% training and 96% operations. The analysis indicated that a better ratio would be 10% training and 90% operations. While there were fewer tons of bombs dropped as a result of this, nevertheless the added training time improved the bombing accuracy so that the bomb weight dropped on the target was doubled. The reader will probably recognize that training problems of this character confront many activities.

6. SURFACE SHIP TACTICS AGAINST KAMIKAZE ATTACKS.

In the Pacific during the latter part of World War II our ships encountered a new weapons system--the Kamikaze. This humanly guided projectile was quite effective in damaging many of our ships. A certain number of these Kamikaze planes were getting by our CAP and AA fire. The counter measures on our part were maneuvering of the ship and intense AA fire. The problem confronting the

Commanding Officer of a ship being attacked by a Kamikaze was: should he maneuver radically in order to spoil the aim of the Kamikaze or should he maneuver less radically in order to maintain the accuracy of his own AA fire control. An analysis of about 500 Kamikaze attacks was made. The resulting analysis indicated that it was best for a large ship to maneuver radically and for a smaller vessel to change course slowly. Also a ship being attacked by a suicide plane coming in from a high dive should present his beam to the incoming plane; a ship being attacked by a plane coming in low should present bow or stern to the plane. In the case of a plane coming in low, the analysis showed that the diminished target area presented to the plane offset the decreased fire power. That this analysis was a correct one is indicated by the following results: Of all ships that were subsequently attacked, those that didn't follow the above recommendations were hit about 47% of the time, while those that did follow these recommendations were hit about 29% of the time.

7. OPERATIONS ANALYSIS IN SUPERMARKETS.

Operations Analysis is not limited to military applications. In fact it has important applications in civilian pursuits and is being recognized more and more in industry as time goes on. There are several operations analysis organizations available to industry now. Recently the operations Research Society of America was founded. More information concerning that will be presented later in this paper.

One example of operations analysis in civilian pursuits is its use in the large business of Supermarkets. In this discussion a supermarket is a retail food store where the customers serve

themselves to most items, and it is a store whose annual volume of business is more than $500,000.00. This particular discussion concerns a chain of supermarkets which is made up of twenty-four such stores. This means a total annual volume of business of more than twelve million dollars. An analyst was called in to study this particular chain, which is located in the Washington-Baltimore area. The problem confronting the analyst was "how to optimize the achievement of purpose". Of course in this case the achievement of purpose was the net income for the stockholders of the firm. This business divides itself into three general functions: (1) buying; (2) storing (3) selling. The net profits to the firm can be increased by smarter buying, by more efficient storage (which includes transportation), and by selling more items at higher prices. There are many rival supermarkets, and the business is extremely competitive. This means that there will not be large benefits from "smart" buying because the rival firms also bid for the products. Similarly, they cannot charge their customers too much, because they will be undersold by their rivals. In fact the different firms employ persons to visit their competitors to see if they are being undersold. The final result is that the store can improve its profits by,(1) making more efficient use of storage space and personnel and by (2) selling <u>more</u> items at the low competitive prices.

Let us consider, first some lessons learned from the storage function. One big item of cost to the supermarket company is that of transportation, which is part of the storage function. As the number of stores increased, it became increasingly more costly to have

different items delivered by the wholesaler to the different stores. It became more economical for the chain of stores to build their own warehouse. All wholesalers would then deliver their products to one central receiving activity. The supermarket company would then use their own trucks and drivers to deliver the groceries needed at the different stores. Each store makes out its requirements on IBM cards which are sent to the main accounting activities and to the warehouse. At the warehouse the men can load a trailer with exactly what is needed for a specified store. An analysis showed the most efficient method of utilizing the trucks and drivers available. For example, if the trucks started moving the loaded trailers at midnight, there would be more truck trips per day, because of the diminished automobile traffic at that time of day. Also, since the stores did about half the week's business during the two day period of Friday and Saturday, it was necessary to arrange the trucking and loading so that the stores would be ready for the sales expected on these two days. Proper loading and trucking of the foods permitted stocking of the stores at the required time. The manager of each store could then arrange the schedule of his own personnel so as to make the most efficient use of them without emergency periods of overtime. Some trucks and drivers also became available for deliveries of perishable items at other times. Greater efficiency in this storage function meant greater efficiency in the over all evolution of the Supermarket business.

Now consider the selling function. Analysis were made on how to improve this by getting the customers to buy more items

and to buy more items which gave a higher profit to the store. This involved arrangements and displays so as to encourage the "impulse sales" idea. Research showed that items which were at eye height on the shelves sold more frequently than those in other positions. Also, items which were in the first row sold many times the number of items carried in other rows, therefore, items which gave a high percent of profit was located here. We all know that the milk is usually located in the back of the store. When we have gone to the store we definitely want the milk. Our going through the other aisles to get to it may remind (or tempt?) us to buy something else. Counters were installed on the turnstiles, and data was collected concerning how many customers were in the store at different times, and concerning how long the average customer remained in the store. This enabled the management to determine when to have more persons stationed at the registers, when to stock the shelves, when to clean the store, etc. The need for operations analysis is indicated in the following: The margin (gross profit percentage) is defined as $\frac{\text{Retail less cost price}}{\text{Retail Price}}$. This ratio is equal to 17%. Out of this increment of 17% must come money for labor, rent, overhead, storage charges, provision for expansion into new stores, and net profit for the stockholders. Almost half of this increment of 17% goes in the form of wages. This points out the importance of efficient utilization of labor. Even more impressive is the following: The net profit for the stockholders must come out of this increment of 17%. The net profit in this organization averages <u>one percent</u>. This means that if a customer pilfers or spoils one dollar's worth of food, the store must sell one hundred dollar's worth

of food to make up for it. Without operations analysis the organization would quickly go bankrupt.

8. JET FIGHTER ACCIDENTS

Another example of the use of operations analysis occurred in connection with the difficulty experienced by USAF pilots in making a parachute jump from a disabled jet fighter. There was a high incidence of head injuries among the pilots who had left disabled jet aircraft. The Operations Analysis Division (USAF) made a study of the probable trajectory of the canopy when released by the pilot prior to his jumping from the aircraft. This study showed that there was a high probability of its hitting the pilot. Recommendations were made to change the design in accordance with these studies. The new designs based upon these studies caused less probability of injury to a pilot who had released the canopy.

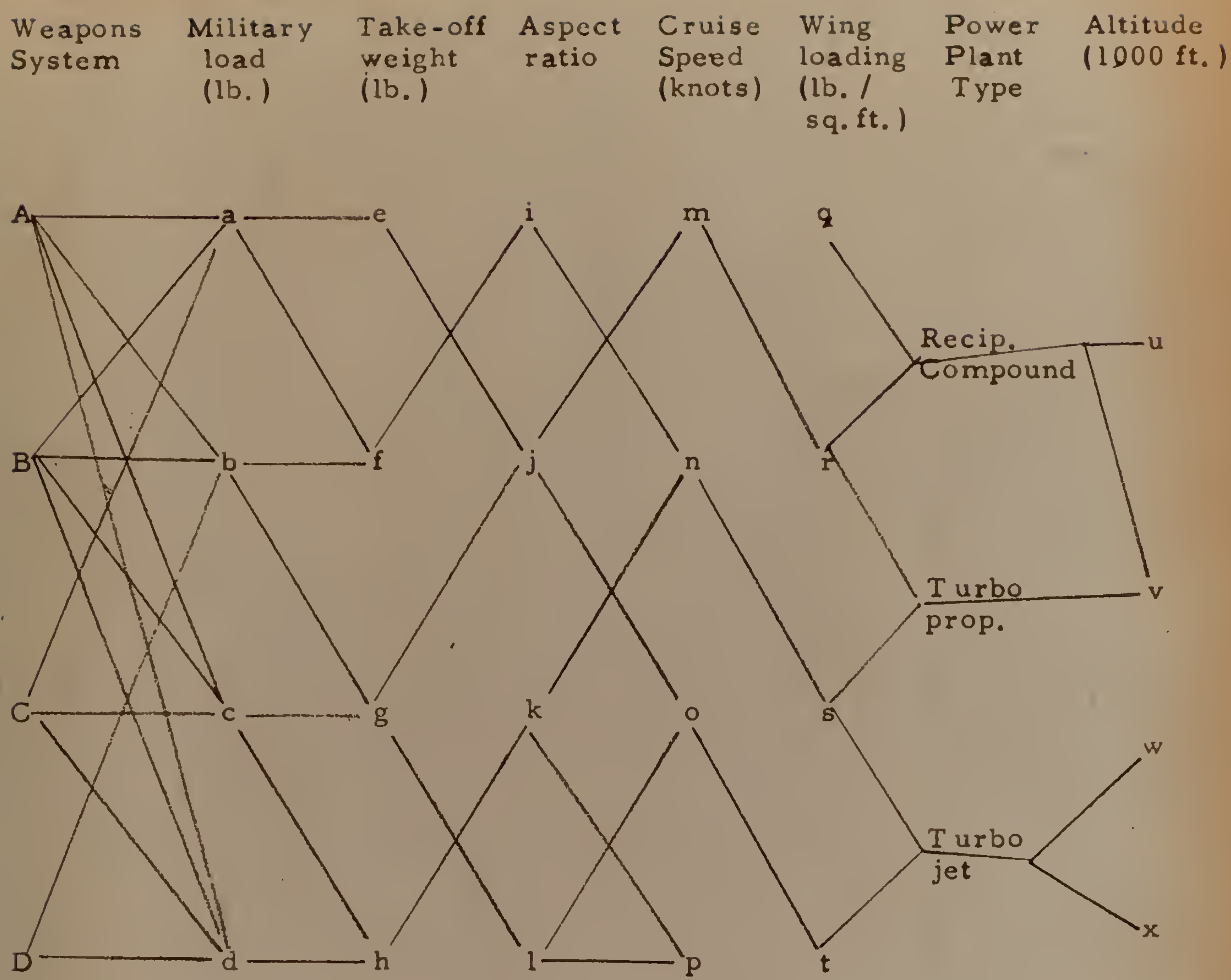
9. OPERATIONS ANALYSIS AND GREEN PEAS.

Another example of the benefits operations analysis is the increased efficiency of operation of the Seabrook Farms, located in southern New Jersey. This is a large farming enterprise which raises vegetables, sorts them, quick-freezes them, and prepares them for delivery to the market. The major problems confronting the management were similar to the following: About seven thousand acres of peas were becoming ripe at the same time. This of course caused a tremendous strain on the entire installation. There were labor problems, which included sudden large demands for labor followed by a decreased need for labor. The quick harvesting also interfered with proper processing (in order to maintain proper standards of quality) and with proper

freezing. The storage problem confronted them too, for it was necessary to place all the products quickly in the refrigerators. Greater efficiency could be obtained if there were some way of maintaining a steady work load rather than one which fluctuates violently. An analysis was made of possible factors, including climatic conditions, moisture content of the soil, sunshine, etc. From this analysis an index was obtained. This index enabled the management to predict quite accurately the maturing rates of peas planted at various times. Since these rates varied with climatic conditions and the time of the year, the amounts planted at various times would be in such quantities that there was always a crop of a fixed size ready to be harvested. This was in turn determined by the capacity of the processing equipment, the freezers, and the storage plant. The new method of operation also provided steady work for the personnel employed by the company. Fewer personnel were required too, because of this greater efficiency.

10. SELECTION OF AIRBORNE WEAPONS SYSTEMS.

An important problem that calls upon operations analysis for its solution is the selection of airborne weapons systems. Suppose that the problem confronting you is the selection of a weapons system (plane plus military load) which is to accomplish a certain mission. The different parameters which could enter into the problem can be indicated in the following table:



This shows that there are many combinations of parameters that can be used to produce many different weapons systems. After the problem had been clearly defined, the analysis would determine a measure of effectiveness. This measure of effectiveness would be calculated for each of the different weapons systems. Thus the optimum system could be determined.

11. MATHEMATICAL CONCEPTS

Some operations analysis problems can be solved by using elementary techniques of mathematics. However the analyst soon finds that he must employ the concepts of probability, statistics,

calculus and beyond. Listed below are some of the areas of mathematics used by the analyst:

Basic algebra and geometry

Probability and Statistics

Differential and integral calculus

Differential equations

Theory of games

Matrices (including the Monte Carlo Method)

Methods of solving linear programming problems

Symbolic logic

Statistical decision functions

CHAPTER V

TRAINING IN OPERATIONS ANALYSIS

Operations analysis (operations research) is a comparatively new field. Those engaged in this field have usually acquired a master's degree in their specialty (mathematics, physics, etc.). Many of this group have also achieved the status of Doctor of Philosophy.

An idea of the training available in civilian institutions may be obtained from the following: On January 22, 1953, the Education Committee of the Operations Research Society of America sent questionnaires to 36 educational institutions in the United States. The following institutions reported that they offered no courses or curricula in operations research (operations analysis) as such but that they did offer some courses related to training in this field: California Institute of Technology, Carnegie Institute of Technology, Stanford University, University of California. Others replied to the questionnaire. In general it appears that these activities offered courses such as statistics, probability theory, etc., which were integral parts of the field of operations research.

The following institutions apparently have progressed further in the direction of offering courses or curricula in operations research:

1. Case Institute of Technology. It reported a curriculum leading to a master's degree in the field.

2. The Johns Hopkins University. An informal seminar was held.

3. Massachusetts Institute of Technology. A 15 day summer course was offered. The lectures assumed a knowledge of calculus and differential equations.

4. Tufts College. It reported a curriculum in the Department of Systems Analysis leading to the degree of Master of Science in Systems Analysis.

5. U. S. Naval Postgraduate School. This offers a curriculum in Operations Analysis leading to the degree of Master of Science. This will be discussed in detail below.

It appears that there is a paucity of courses and curricula offered in the field of Operations Research. Some reasons for this may be the following: (1) the relatively short time that has been available since the end of World War II to introduce courses and curricula, (2) the normal conservatism of universities in admitting new disciplines, (3) the question of what operations analysis really is and what it is really supposed to do. In connection with this last comment, there are indications that analysts will readily argue at great length among themselves, each asserting his own definition of operations research.

6. The Operations Analysis Course offered by the U. S. Naval Postgraduate School.

The U. S. Naval Postgraduate School at Monterey, California, offers a two year course in Operations Analysis, leading to the degree, Master of Science. Annually a board selects from those officers who

have applied for this course the required number who are apparently best qualified. The objective of this course is quoted from the Catalogue of the U. S. Naval Postgraduate School, Academic Year 1953-1954: "To educate officers in the basic sciences and to provide a thorough grounding in the theory and methods of operations analysis in order that they may direct the analytical approach to complex naval problems."

CHAPTER VI

AN OPERATIONS ANALYSIS PROBLEM FOR THE READER

The Situation:

You are a member of the staff of a submarine task force commander. His mission is: With the number of submarines available to him to sink a maximum number of enemy merchant vessels in an assigned area "A" in the Atlantic. The number of square miles in this area is 200,000 square miles.

Your problem: Develop a measure of effectiveness which will show the task force commander the effectiveness of his force and which might also reveal other information concerning the enemy.

For purposes of this problem assume that you have collected data for two equal periods of time as indicated in the following table:

Period of time		I	II
Average no. enemy ships present in the area. (Based on intelligence estimates of no. ships passing through the area)	(N)	80	100
Sub-days in the area	(T)	300	500
No. contacts	(C)	240	150

Note: Assume that the average patrol for a submarine is 200 miles per day. Also assume that a submarine definitely contacts all surface targets that come within 7.5 miles of it.

The solution:

There the measure of effectiveness is "comparison of the theoretical <u>sweep rate</u> with the operational <u>sweep rate</u>."

Theoretical sweep rate is developed as follows: If a sub patrols 200 miles per day and positively contacts all targets 7.5 miles on either beam, then his theoretical sweep rate is 2 x 7.5 x 200, which equals 3000 square miles per day.

Operational sweep rate is developed as follows:

Let "N" represent the average number of enemy ships present in the area. This number is an estimate based upon intelligence reports of ship sailings, flow of tons of materials shipped, available routes, etc.

Let "T" represent the number of sub-days in the area. This depends upon the number of submarines available to the task force commander and the number of days each sub patrols on station.

Let "C" represent the number of contacts made during a given period.

Let "A" represent the area searched over in square miles.

Now consider the expression: $$\frac{C \times A}{N \times T}$$

Its units are: $$\frac{\text{Ships contacted} \times \text{square miles}}{\text{Ships in the area} \times \text{sub days in the area}}$$

This is equivalent to square miles per day for a submarine. These units are those of a sweep rate. This is an "operational sweep rate." Thus we have an operational sweep rate to be compared with a theoretical sweep rate. Both have the units of "square miles per day."

Now let us consider the actual problem:

The theoretical sweep rate equals 2 x 7.5 x 200 which amounts to 3000 square miles per day.

The operational sweep rate for period I is:

$$\frac{C \times A}{N \times T} = \frac{240 \times 200,000}{80 \times 300} = 2000 \text{ square miles per day}$$

The operational sweep rate for period II is:

$$\frac{C \times A}{N \times T} = \frac{150 \times 200,000}{100 \times 500} = 600 \text{ square miles per day.}$$

Note that the operational sweep rate for period I is a little less than the theoretical sweep rate. Also note that the operational sweep rate for period II is about one-fifth as large as the theoretical sweep rate.

Now we can analyze possible reasons for the differences in these sweep rates.

(a) If we assume that the data given in the table are accurate, then we might deduce the following:

(1) The subs during period II were not as efficient as during period I. This might be a reflection on state of training, fatigue of personnel, or other personnel factors.

(2) The detection equipment being used by the subs during period II was not as efficient as during period I.

(3) The enemy had changed his tactics. His merchant vessels were not uniformly distributed through the area. This might mean also that he has shifted the routes of his ships to pass through other areas.

(b) If the operational sweep rate were greater than the theoretical sweep rate we might infer that:

(1) The enemy is sending his ships through certain selected areas rather than distributing their routes at random.

(2) Our intelligence estimates were in error.

Thus the sweep rate concept is an example of a measure of effectiveness which helps the task force commander and others to optimize the achievement of their purpose.

CHAPTER VII

CLASSIFIED SOURCES OF INFORMATION

Most of the operations analysis performed by the various activities is classified. Reference to this classified matter was not included in this paper because then the distribution of this paper would be greatly restricted.

A more complete picture can be obtained by consulting reports and studies by the following activities: Operations Evaluation Group (U. S. Navy), Operations Research Office (U. S. Army), Operations Analysis Division (U. S. Air Force), Operational Development Force. Many of these publications are available in the Library of the U. S. Naval Postgraduate School.

The writer recommends that the above publications be examined in order to obtain a fuller appreciation of what benefits are derived by the armed forces from operations analysis.

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